Kisch – Infiltration through liners and caps

1 Introduction

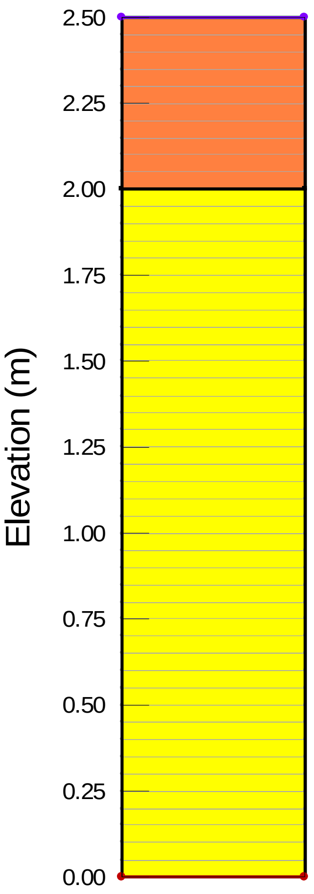
The objective of this illustration is to compare a computed steady state solution for fully unsaturated flow with a known solution. In addition, it will be shown that flow across a capillary break depends on the pressure profile established below the break location.

2 Feature highlights

GeoStudio feature highlights include:

- Non-linear unsaturated flow
- Verification with closed form solution
- Capillary breaks beneath caps and liners
- Unit gradient boundary conditions beneath a cap layer

3 Geometry and boundary conditions



A common technique for reducing the seepage loss from a reservoir is to line the reservoir with a clay blanket. Alternately, a compacted cap layer near the ground surface can limit infiltration into underlying waste material below. If the waste is coarser in nature relative to the cap material, a capillary break phenomenon often results.

The problem is challenging to analyze because of the sharp contrast in the saturated hydraulic conductivity of the compacted material and that of the underlying material. As well, the underlying material is often sandy, with a very steep hydraulic conductivity function that requires a robust, iterative numerical solution.

A relatively simple finite element model can be set up to investigate this phenomenon, as shown in the figure on the left. The model is 2.5 meters high and comprised of a 0.5 m compacted layer, on top of a 2m more coarse layer.

In one analysis, the top and bottom of the model are set to have a zero pressure boundary condition. At the surface, this implies a thin film of free water, which can infiltrate at a rate controlled by the soil properties. At the base, a water table location is implied.

In a second analysis, the bottom boundary condition is replaced with a unit gradient condition, which implies that the specific location of the water table is not known. This may be the case for percolation through a cap over waste.

4 Material properties

Kisch, (1959, pp. 9 21), studied this problem and developed closed form solutions. Hydraulic conductivity data was obtained for a Yalo Light Clay and for a Superstition Sand. The functions are illustrated in Figure 1. The saturated conductivity of the clay is about 1e-7 m/sec, and just over 2 orders of magnitude less than that of the sand at 1.1e-5 m/sec. The functions are only illustrated over a small suction range of 10 kPa, but they would be fully defined over a much larger range than that for a field application.

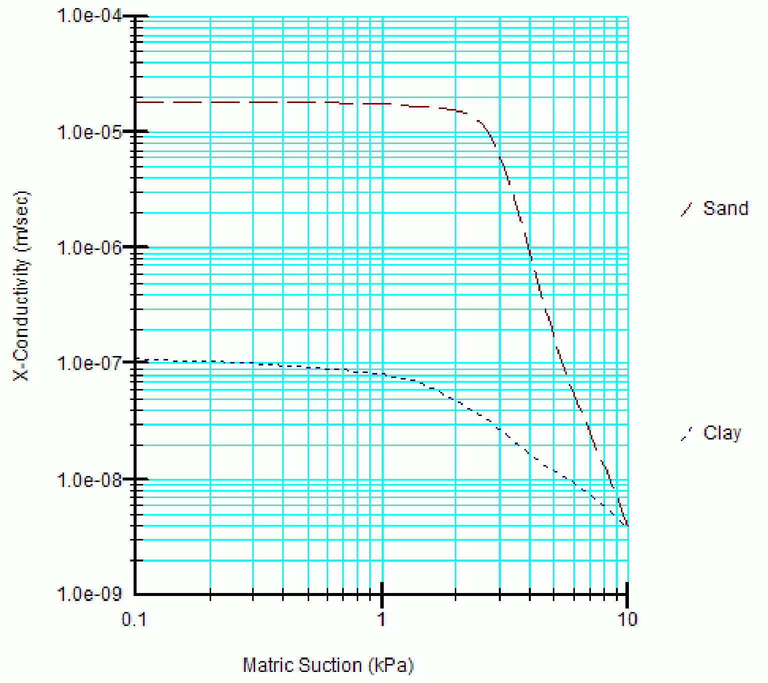


Figure 1 Conductivity functions for Kisch solution

5 Discussion of results

Kisch's work indicated that the pore-water pressure distribution in the clay blanket and in the underlying sand is as illustrated in Figure 2. When the water level in the pond is at the surface of the clay blanket, the flow through the system is in an unsaturated state down to a water table in the sand. The pore-water pressure decreases sharply at the clay-sand contact, and remains at a constant value down to the capillary zone in the sand.

VADOSE/W is capable of computing the negative pore-water pressure distribution as predicted by Kisch. Figure 3 shows the solution for the case where the flow system is assumed to be a clay liner at the base of a pond that is some elevation above a water table. The solution matches the Kisch published solution very well.

To obtain a solution to this highly non-linear problem, it is necessary to use many iterations and control the change in hydraulic conductivity from one iteration to the next. The solution scheme incorporated in VADOSE/W allows you to specify how the hydraulic conductivity should be changed between iterations.

Figure 4 shows the results for the unit gradient version of the same analysis. The form and shape of the pore-water pressure distribution is the same as the closed-form solution predicted by Kisch. The VADOSE/W distribution is slightly more gradual in the transition zone between the clay and sand interface than Kisch's prediction. This difference is minor, however, considering the extreme non-linearity of the flow system due to the steep hydraulic conductivity function of the sand.

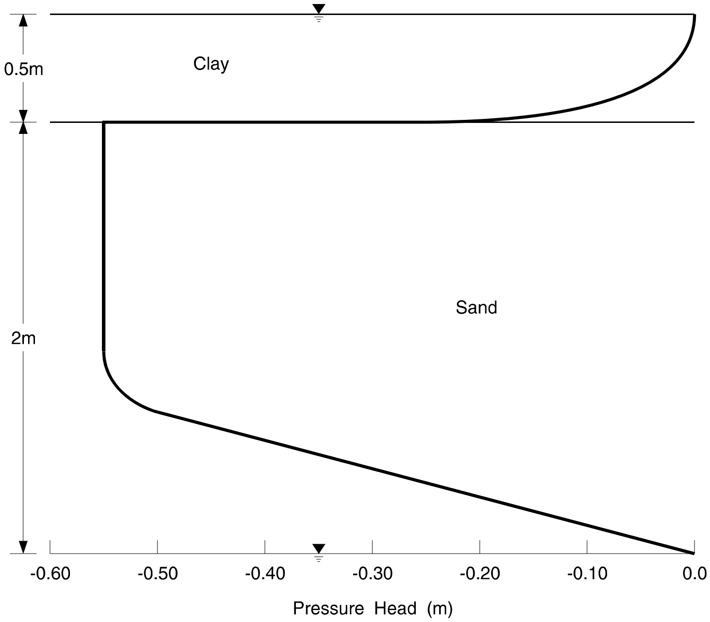


Figure 2 Kisch published solution for pressure beneath a liner

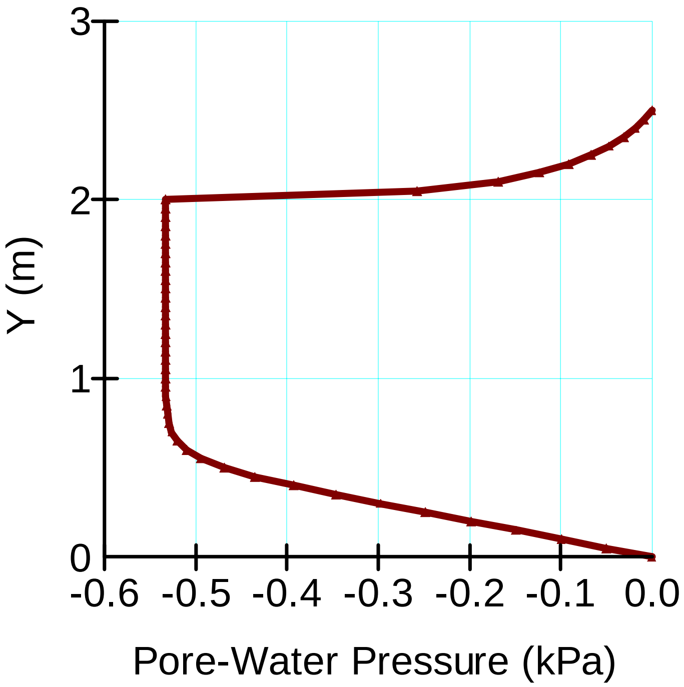


Figure 3 Computed for liner above a water table

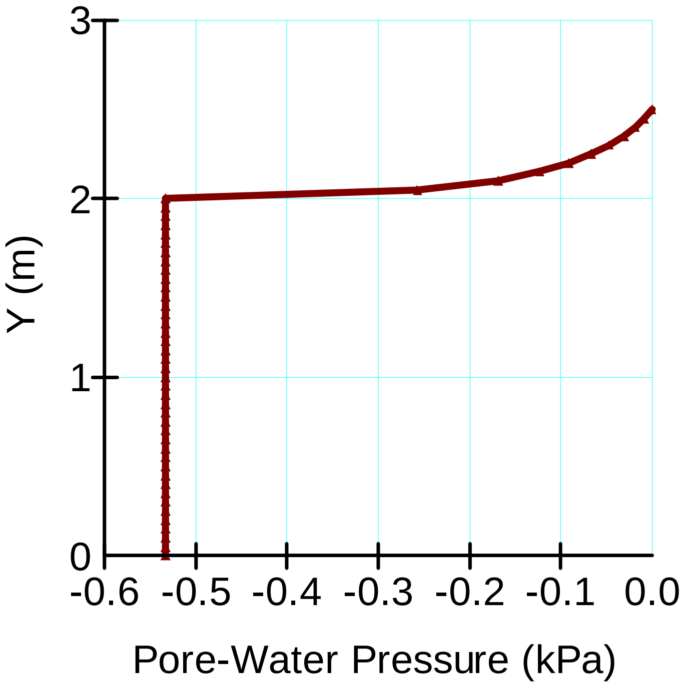


Figure 4 Computed for a unit gradient in waste below a cap

It is important to see that for the unit gradient case, where neither equilibrium pressure nor depth to water table is known, a good solution can be obtained. This type of unit gradient boundary condition can be used as long as it is placed far enough below the controlling conductivity material, such that the presence of the boundary condition does not adversely affect the solution. Typical uses for this unit gradient boundary condition would be flow through a liner (as illustrated in this example, and also flow through a soil cover system designed to limit infiltration into mine, municipal and hazardous waste dumps.

This example shows that VADOSE/W can be used to analyze unsaturated flow in materials with extremely steep hydraulic conductivity functions. However, the analysis may require a fine mesh and a large number of iterations.